SN# S00901-05A5

Mini

AUTOCORRELATOR

Manual

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1. Description

1.1. Introduction

The **MINI** autocorrelator is a compact instrument used to measure the temporal width of light pulses emitted from mode-locked lasers. Measurements of picosecond and femtosecond pulses, at either high or low repetition rate, can be made routinely to aid in monitoring laser performance.

Autocorrelation techniques, typically, are used to characterize light pulses produced by modern ultrafast laser systems because, generally, the duration of the light pulse is too short to be measured by electronic detectors directly.

Autocorrelation techniques that rely on second harmonic generation in a nonlinear crystal require that two beams with proper polarization come to a focus at the same spot, both spatially and temporally, in a nonlinear crystal that is tilted to the correct angle for phasematching. The **MINI** autocorrelator makes the optimization of these variables rather simple and easy to do.

In the **MINI** autocorrelator, a pulse is split into two replica parts and then recombined in a nonlinear mixing crystal after the two parts have experienced a known relative time delay. Because the mixing crystal produces a measurable light signal when the pulses overlap temporally, the variation of the signal as a function of delay time can be used as a measure of pulse width. By using multiple pulses, with the relative delay between the split pulses being changed on a relatively slow time scale, a plot of overlap versus delay is generated. This plot is the autocorrelation function (ACF) of a typical pulse.

1.2. Features

At the heart of each **MINI** autocorrelator is a state-of-the art linear delay drive with integrated high-resolution position readout.

Each autocorrelator features an optical layout that requires a minimum of adjustment and the use of all reflective optics for the highest possible time resolution.

The measurement range is from femtoseconds up through several picoseconds with a number of standard wavelength ranges available.

Attractive standard features of the **MINI** include a monochrome liquid crystal display, choice of scan modes, and computer compatibility. Inclusion of an LCD display into the standard unit means that the measurement process is self-contained so that an autocorrelation trace can be visualized without an oscilloscope. Incorporation of a triggered scan mode allows the system to measure pulses from ultrafast lasers of any repetition rate -- oscillator or regenerative amplifier. In addition, the RS-232 interface permits datatransfer to a computer terminal.

Power to the instrument is provided by a universal adapter that operates from most line voltages worldwide.

1.3. Specifications

Optical parameters

- Scan ranges (selectable by front panel switch)	128 fsec, 512 fsec, 1.54 psec, 5.12 psec, 15.4 psec
- Resolution	better than 1 fsec
- Linearity	better than 1 %
- Scan frequency	approx. 16 Hz
- Input polarization required	horizontal (electric vector) (a polarization rotator is available from APE)
- Standard wavelength ranges (contact APE for other ranges).	„VIS I" 420 ... 550 nm, „VIS II" 520 ... 750 nm, „NIR" 700 ... 1100 nm, or „IR" 1000 ... 1600 nm
- Sensitivity ($P_{average} * P_{peak}$)	10^{-4} W^2 (PMT) 100 W^2 (PD)
- Input beam height	adjustable over a range of 75 - 115 mm

Electrical parameters

- Power supply	15 V / 700 mA (a plug-in power supply that operates from 100 V ... 240 V line is supplied with the system)
- Outputs	x (delay) approx. 0 ... 5 V analog y (signal) approx. 0 ... 5 V analog serial interface RS 232
- Trigger input	TTL, f < 10 kHz

Mechanical parameters

- Sizes (H x W x D)	
Optical unit	104 x 141 x 111 mm^3
(Alignment Base, max.)	62 x 148 x 132 mm^3
Control electronics	97 x 153 x 147 mm^3
Approx. shipping weight	5 kg

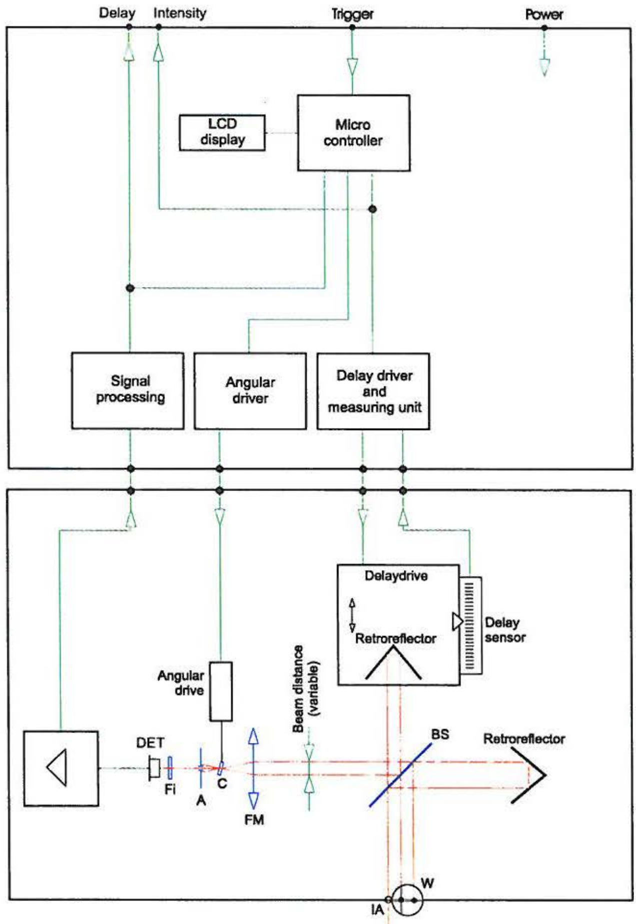
2. Principle of Operation

2.1. System Overview

The **MINI** autocorrelator consists of an Optical Assembly and an Electronic Controller as shown in figure 1. The Optical Assembly, shown on the left in Figure 1, contains a Michelson-Interferometer, delay stage, nonlinear crystal, filter, and detector. In some special versions of the **MINI**, the crystal, filter, and detector are replaced by a two-photon detector. The Electronic Controller drives the delay stage, processes the autocorrelation signal, and displays the Autocorrelation Function (ACF).

Fig. 1 Optic and control electronics

Fig. 2 shows the optical schematic of the Optical Assembly and the main electronic modules of the Electronic Controller.



IA	-	Input aperture
W	-	Control window
BS	-	Beamsplitter
FM	-	Focus mirror
C	-	Ultrathin SHG-crystal (100/40 mm)
A	-	Aperture
Fi	-	Filter
DET	-	Detector

Fig. 2

2.2. Optical Assembly

2.2.1. Overview

The optics unit with alignment base is shown in fig. 3.

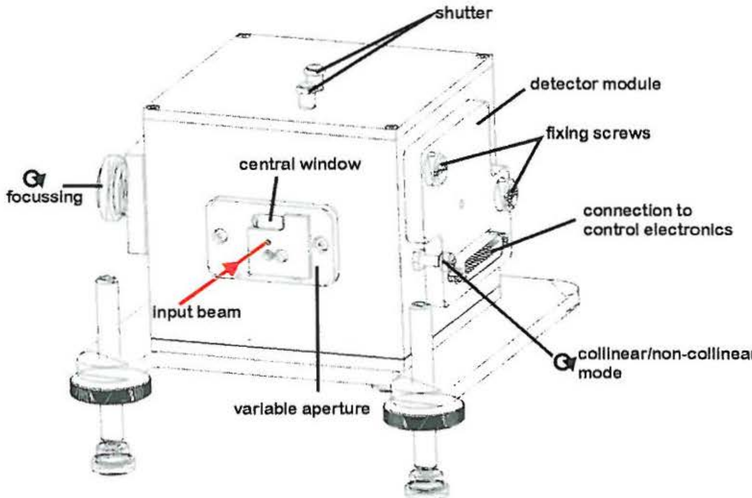


Fig. 3 Optics unit

The optical beam path can be traced in Figure 2. Entering the optical assembly at the input aperture, the laser pulse is divided into two parts at the beamsplitter. Each part traverses an interferometer arm containing a retroreflector. One of the retroreflectors is mounted on a special linear translation stage that can change the length of one interferometer arm in a continuous fashion. The two replica pulses then are recombined by the beam splitter, focussed by a mirror, and overlapped in a nonlinear optical crystal. Light generated in the nonlinear crystal is then detected by a filtered photomultiplier tube.

A portion of the back-reflected beams can be seen on the window next to the input aperture and are used for alignment of the beam into the autocorrelator.

2.2.2. Time Delay

The time delay for generation of the autocorrelation trace is introduced by movement of a retroreflector mounted on a linear delay stage.

Whenever the instrument is turned on, the delay stage will be oscillating at its resonant frequency of approximately 26 Hz.

A voltage, proportional to the scaled position of the delay stage, is available at the „X" BNC connector at the rear panel of the Electronic Controller.

2.2.3. Mixing Crystal

When tilted to the proper angle, a small amount of frequency doubled light is generated in the nonlinear crystal.

In collinear geometry, the two replica pulses follow the same beam path and generate second harmonic light whether or not they overlap temporally. The intensity contrast between exactly overlapped pulses and pulses with no overlap is 3:1.

In non-collinear geometry, only the second harmonic light produced by temporal overlap is detected. Hence, the contrast between exactly overlapped pulses and pulses with no overlap is infinite.

Normally, the nonlinear crystal is inaccessible because it is slightly hygroscopic and can become fogged by high humidity. However, should the crystal need to be cleaned or exchanged, it can be accessed by removal of the upper cover of the optical assembly.

The crystal is mounted magnetically; additional magnetic mounts can be ordered from APE GmbH Berlin.

2.2.4. Signal Detection

Second harmonic light, generated in the mixing crystal is detected by a Photomultiplier tube, which has been filtered to block transmission of light at the wavelength of the laser. The photomultiplier tube converts

light intensity into an electronic signal. This signal is then electronically amplified and filtered, and is available at the „Y" BNC connector at the rear panel of the Electronic Controller.

2.3. Electronic Controller

2.3.1. Front Panel

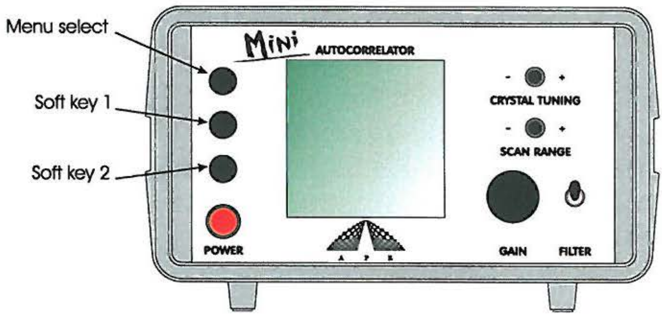


Fig. 4 Front panel

The front panel of the control electronics is shown in fig. 4. The „GAIN" rotary knob controls the PMT voltage. Scan range, crystal tilt, and filter selection are adjusted by the corresponding momentary switches.

Soft keys operate on variables that are dependent on the software menu selected. The current settings of all controls are shown in the display.

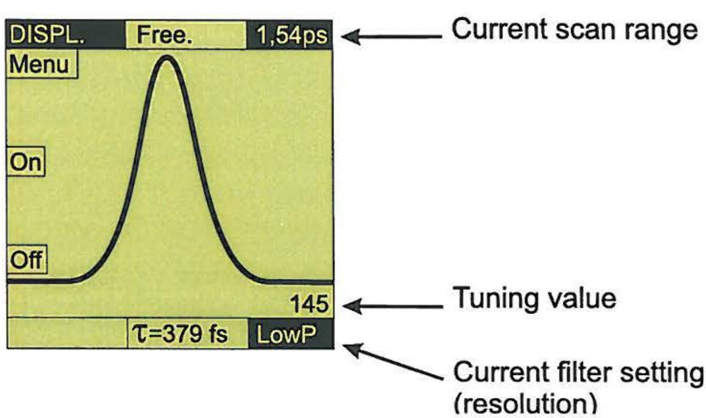


Fig. 5 Display

2.3.1.1. Delay Stage Scan Range

The delay scan range is selected by momentary action of the front panel switch. Scan ranges of either 128 fsec, 512 fsec, 1.54 psec, 5.12 psec or 15.4 psec can be selected by action of this switch. The actual scan range is displayed on the LCD screen.

The delay introduced by movement of the linear translation stage is measured by special circuitry. The circuitry converts the positional delay into a voltage, which is used, via an electronic feedback circuit, to stabilize the scan range.

The scan ranges displayed on the LCD screen are calibrated with high accuracy. However, the accuracy of the FWHM readout is limited by the 8-bit resolution of the AD-Converter (+/- 0.5% of actual scan range).

An analog ACF as displayed on an oscilloscope with the analog signals at the X and Y BNC connectors on the rear panel does not show these digitizing effects. ON the other hand the calibration of the analog delay output is not calibrated due to a certain "overscan" (actual scan range + 5% appr.).

When the scan range is changed, it takes about 20 sec for the motion of the delay stage to stabilize to the new settings.

2.3.1.2. Crystal Tuning

The crystal can be angularly tilted for phasematching by action of the front panel switch.

Setting the proper crystal angle can be done with the optical assembly in either the collinear or non-collinear configuration. In the collinear configuration, if the crystal is tilted properly, there is a background SHG signal even when the replica pulses do not overlap in time. Since the crystal tilt for the collinear configuration is nearly the same as the tilt for the non-collinear configuration, the collinear configuration is a convenient starting point for alignment of the autocorrelator.

When the wavelength is changed or when the configuration is changed between collinear and noncollinear, the crystal tilt will need to be reoptimized.

2.3.1.3. Photomultiplier Voltage

Photomultiplier voltage is set with the large knob on the front panel. Photomultipliers are very sensitive detectors of low light levels; the signal from the photomultiplier scales nonlinearly as a power of the high voltage setting.

2.3.1.4. Signal Electronic Filtering

The photomultiplier signal can be electronically filtered. In situations where fast response is important, the electronics are set to pass high frequency events. In other instances, in which the signals are slowly varying and perhaps are noisy due to low light levels, the electronic circuitry is set to a low pass condition.

Placing the switch in the UP position sets the electronic filter for low pass.

To measure a fringe-resolved ACF in the FREE RUN acquisition mode, the filter has to be switched off so that the high frequency fringes can be detected. Such a measurement can only be done with fsec pulses with the optical configuration set for the collinear mode. Fringe-resolved signals can be observed on an oscilloscope, using the X and Y outputs from the rear panel of the autocorrelator. However, the LCD display is too coarse to display a fringe-resolved autocorrelation trace.

In the FRINGES mode of data acquisition, the LCD display shows the envelope of the true fringe-resolved autocorrelation trace. With the filter ON, display resolution decreases from 128 to 64. Such a setting smoothes the envelope function.

In the TRIGG mode of data acquisition, the filter will automatically be set for high pass and the front panel switch has no effect.

2.3.2. Rear Panel

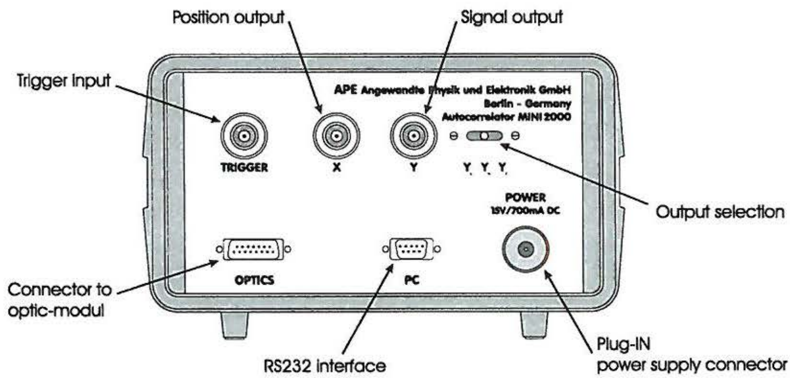


Fig. 6

For obtaining an autocorrelation trace from a low repetition rate laser, an external trigger initiates data collection. Intensity data (Y) is captured immediately following the trigger signal and is paired with the position of the delay stage (X). The data acquisition mode is switched to TRIGG by action of the soft keys on the front panel when measuring low repetition rate lasers.

An alternate method of displaying the autocorrelation trace is to use an oscilloscope in XY mode, using the signals at the rear panel „X" and „Y" BNC connectors. The Y-signal can be set according to the selected data acquisition mode

Y_L AC signal with Lowpass filter
Y_H without Lowpass filter
Y_T after triggered acquisition

In addition, the position of the delay stage can be monitored via the voltage at the „X" BNC connector on the rear panel of the Electronic Controller. This voltage is scaled to the scan range selected by front panel control, such that 0 to maximum voltage (approx. 5 V) corresponds to the total scan range setting + 5% (not calibrated). Because of the dynamics of driving the delay stage, there will be some variability in the exact extent of each scan. However, since autocorrelation

data is collected by saving individual X,Y pairs of data points, an exact delay time is associated each intensity point so that the autocorrelation trace is exceedingly accurate.

Connection to the optical assembly is made with a cable attached to the 15-pin connector on the rear panel. A 9-pin connector allows one to connect the controller to a computer via a serial interface. The ACF and measurement parameters can be transferred to the PC.

A special power supply is provided for powering the electronic controller, and plugs into the rear panel of the controller.

2.3.3. Software

The function of the soft keys depends on the selected menu. The following sections describe menus that are activated by the „Menu select“ button. Please, note that the controller responds only when a button is released.

2.3.3.1. Display Menu

Display of the autocorrelation function can be switched ON or OFF. Switching the autocorrelation function OFF is useful when using the FWHM mode.

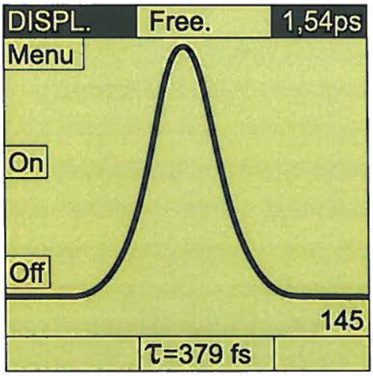


Fig. 7

2.3.3.2. Data Acquisition Menu

One of three data acquisition modes -- FREE RUN, TRIGG, or FRINGES -- can be chosen by the „+"/ „-" soft keys.

- FREE RUN is used for continuous measurement of lasers with high repetition rates. Delay position and SHG signal are continuously measured, digitized and saved. This information is then processed and displayed as the autocorrelation function on the LCD display.
- TRIGG is used for ‚triggered' measurements of lasers with repetition rates < 5 kHz. In this mode a trigger signal must be input at the rear panel BNC connector. A trigger pulse initiates capture of intensity information and delay position. At lower repetition rates, the autocorrelation function will take longer to „fill in" and it will take longer for the trace to be updated. Obviously, if the autocorrelator is put into this acquisition mode and no trigger pulse is applied, no autocorrelation trace can be displayed. Because the detector must respond to pulses, the electronic filter is automatically set to high and the front panel filter switch is disabled.
- FRINGES is used when taking fringe-resolved autocorrelation traces. This mode is used with a collinear optical configuration. Because of limited display resolution, the LCD display will show the envelope of the fringes. To get a smooth envelope function, the average value is automatically set to 16; the display resolution can be decreased from 128 to 64 by switching the filter on.

The selected data acquisition mode is shown on the display (see fig.8).

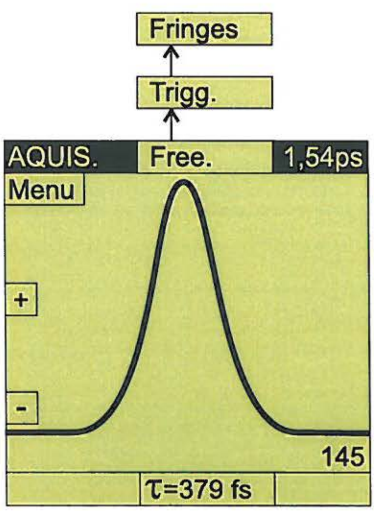


Fig. 8

2.3.3.3. FWHM Menu

When this function is activated, the calculated Full Width at Half Maximum (FWHM) of the autocorrelation function is shown on the display. The accuracy of the FWHM is limited by the resolution of the AD-convertion (+/- 0.5% of actual scan range).

Due to the principle of the autocorrelation technique, typically, the FWHM of the actual laser pulse is smaller by a form factor, (depending on the actual shape of the laser pulse, i.e. 0.71 for Gaussian pulses or 0.65 for $sech^2$-shaped pulses)

The time delay difference between the 50% intensity points of the autocorrelation function is displayed as the FWHM of the autocorrelation function. For this calculation, the zero value is taken as the intensity at the left edge of the display.

Please ensure that you always have the complete ACF, including the wings, on the screen so that an accurate FWHM can be calculated.

When display of the ACF is turned off, the FWHM value is displayed in a large font together with a bargraph.

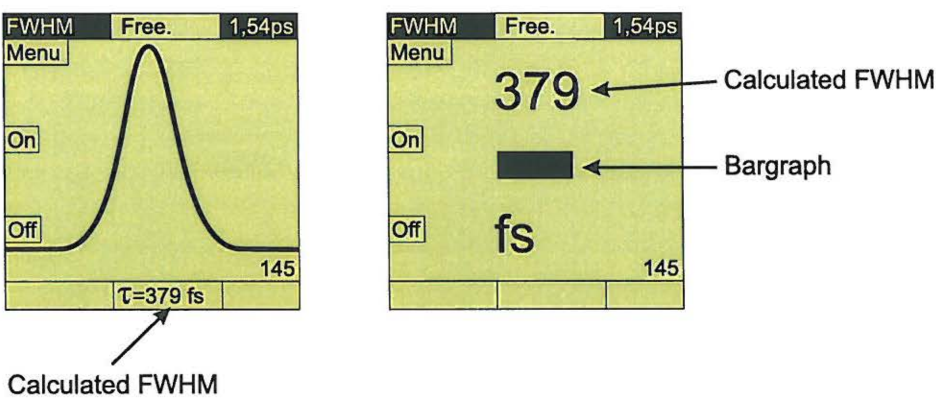


Fig. 9

2.3.3.4. Average Menu

The AVER function determines the number of autocorrelation functions that are acquired before being displayed. As the average number is increased, the refresh rate of the display is decreased. The AVER number can be changed by pressing the „+“/“-“ soft keys; the current average value is shown on the display.

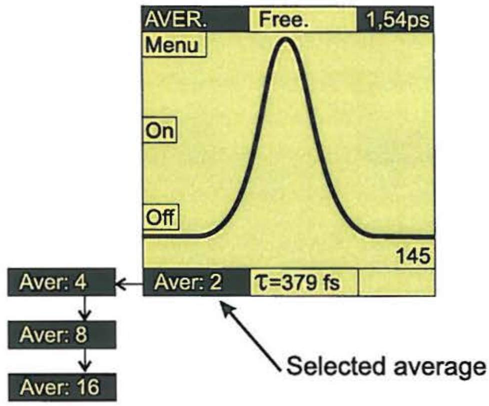


Fig. 10

2.3.3.5. Signal Offset Menu

This function adds an electronic offset to the signal. Such an offset moves the ACF vertically on the screen. The signal offset is displayed on the screen when this menu is active.

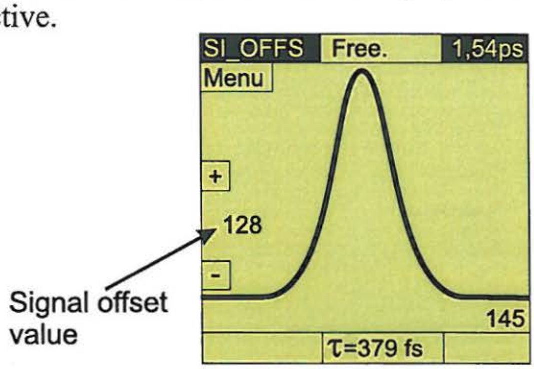


Fig. 11

2.3.3.6. Scanner Offset Menu

This function adds an electronic offset to the scan delay. This offset moves the ACF horizontally on the screen. With this function, it is possible to center the ACF on the screen. The scanner offset is displayed when this menu is active.

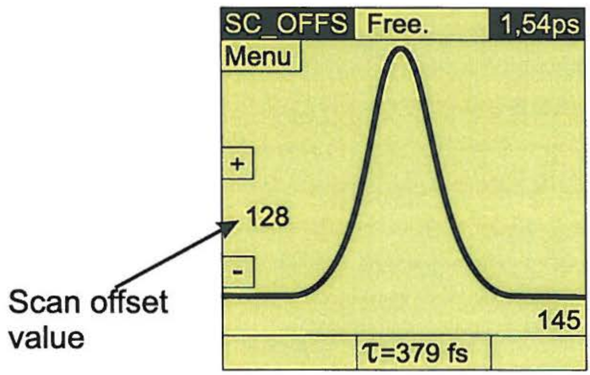


Fig. 12

2.3.3.7. Contrast Menu

Display brightness can be increased or decreased by using the „+“/“-“ soft keys of this menu.

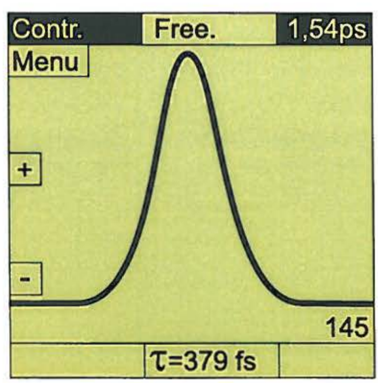


Fig. 13

3. Installation

If the system has been shipped during the cold winter months, please, allow time for the instrument to warm slowly to the temperature of the laboratory.

3.1. Cabling

Interconnect the optical unit and control electronics with the 15-pin cable provided. Connect the electronics to the mains, using the AC adapter.

3.2. Input Alignment

3.2.1. Baseplate Attachment

Attach the baseplate to the optical assembly, level the unit, and lock down the adjustment feet.

1. Screw the feet into the base plate as shown in Figure 1.
2. Place the optical unit onto the baseplate, aligning the hole underneath the control window with the pin in the baseplate.
3. Using the M6 screw provided, attach the optical unit to the base plate. ATTENTION! Do not drive this screw into the bottom hole without the base plate and the washers. For post mounting, the maximum length of exposed thread is 6 mm. Using a longer thread can cause serious damage to the device.
4. Level the base plate at the appropriate height.

3.2.2. Input Laser Beam Alignment

Direct a portion of the laser beam toward the autocorrelator, using an appropriate optical element (glass plate, mirror, etc.) mounted in a good mirror mount. The beam should enter through the input aperture of the autocorrelator nearly perpendicular to the unit. The input beam must

have horizontal polarization, in order to satisfy the phasematch condition of the nonlinear crystal, and have low angular divergence.

Bring the back reflection of the beam on the cross wires at the control window by alignment of the optical unit. If there are 2 back reflections (noncollinear interaction) they can be united by pushing the knob „INTERACTION TYPE“ (see fig. 3).

Twisting the optical assembly in the horizontal plane will move the back reflection in the horizontal plane and tilting the optical assembly up or down will move the back reflection up or down.

Once the optical assembly is grossly aligned, it should be clamped to the table. Final adjustments can be made by adjustment of the mirror mount that holds the sampling element.

3.3. Collinear Autocorrelation

Although it is often preferred to operate the autocorrelator in the background-free, or non-collinear mode, it is sometimes easier to find an autocorrelation signal in the collinear mode. If one has trouble finding the autocorrelation trace, then push the side knob, see figure 3, all the way in for collinear operation. In collinear mode, you are assured of seeing a signal from the autocorrelator if the crystal is aligned at the proper angle, even if the two replica beams do not overlap temporally or spatially. Hence, due to the fewer variables involved, it is best to use this collinear configuration to begin an optimization of the autocorrelation trace.

3.4. Find the Autocorrelation Trace

- Switch the autocorrelator ON.
- After an initialization period (warm up is displayed), the unit is ready for measurement with a „1.54 psec“ scan range.
- At first you will see a flat horizontal line over the whole screen. Slowly increase the „GAIN“ until either a clear signal or noise is observed. If

the autocorrelator is responding to room lights, dim the lights or block off the source of external light to the autocorrelator.

- Rotate the crystal by using the front panel switch to find the optimal angle. An optimally aligned crystal is characterized by a clear, angle dependent signal maximum. The actual angle value for the crystal is shown near the bottom of the display. If a limit is reached such that the numbered displayed is no longer changing, then reverse the drive direction.
- Many laser sources have a small portion of second harmonic light coincident with the fundamental laser pulse, and this small amount of light may swamp the second harmonic signal that is generated by the thin crystal inside the autocorrelator. A remedy to this problem is to insert a long pass filter into the laser beam such that the fundamental wavelength is transmitted and wavelengths in the vicinity of the second harmonic are blocked.
- As a check for the real autocorrelation signal, block one of the beams of the Michelson-Interferometer inside the autocorrelator. This can be done by rotation of the knob on top of the autocorrelator in the clockwise or counterclockwise direction. Blocking either beam individually will eliminate the signal originating from the interaction of the two beams with one another. In addition, it will reduce the background away from the peak by 50%.
- Optimize the peak and the peak-to-background ratio of the autocorrelation signal through adjustment of the crystal tilt, focus, scan range, and filter.
- If there is no angle dependent signal or no peak, check that there is no stray light from the laser beam by inserting a long pass filter into the beam. Additionally, go back and recheck the alignment such that there is a back reflection at the cross wires, that the input polarization is horizontal, and that the laser is mode-locked.
- If the autocorrelation signal goes off scale, then decrease the „GAIN“ and/or decrease the laser input power (ND-filters, lower reflectivity of the coupling element etc.).

3.5. Non-Collinear Autocorrelation

Set the instrument to the collinear autocorrelation mode. Gradually, move from the collinear configuration to the non-collinear configuration. By partially withdrawing the side knob, see figure 3, a configuration intermediate between collinear and non-collinear can be chosen. The beam separation distance can be monitored directly at the control window. In the non-collinear case the second (movable) back reflection will be to the left side of the cross hairs. While changing the beam distance, make sure to optimize the sensitivity, the phase matching angle, and the focus adjustment.

4. Daily Operation

1. Switch-on the autocorrelator and wait for the instrument to finish its initialization regimen.
2. Check the alignment.
3. Read the autocorrelation trace.
4. Remember, if the wavelength is changed, the phase matching angle will need to be changed. In addition, the GAIN and focusing adjustment may require reoptimization.

5. Troubleshooting

Check for Correct Input Polarization

The input beam must be horizontally polarized in order for the crystal phasematching condition to be satisfied. The polarization can be rotated by a half-wave retardation plate, but be aware that the retardation may change with wavelength. Alternatively, one can use a broadband pair of mirrors, mounted @ 45° to the beam; such an assembly can be ordered from APE GmbH Berlin.

Avoid extraneous light on the Photomultiplier Tube

At very extreme wavelengths and input power levels the ACF can be swamped out by a larger background from either the fundamental wave or some second harmonic light that propagates with the laser beam in the collinear case. These situations can be avoided either by using the noncollinear interaction or by using a long pass filter or detector. Please contact APE or INRAD for assistance.

Error characteristics	Possible reason	Check and removal
No SHG- signal	Wrong polarization direction	Check with polarization rotator. Introduce polarization rotator within input beam.
	Wrong alignment	Check beam position at input aperture. Check back reflection at the control window. Check focussing. Check phase matching.
	No or too long input pulses	Check with an independent method. (fast photodiode, spectral width etc.)
	Input power too small	Increase PMT gain.
	Delay zero-position outside scan range	Check at wider scan ranges. Compensate with "SCANOFFSET".
No clear ACF	Wrong Scan range	Check at wider scan ranges.
	No or too long input pulses	Check with an independent method. (fast photodiode, spectral width etc.)

Background-signal without ACF-peak	Wrong alignment in non-collinear case (one beam directed to detector aperture)	Check with “SHUTTER”, reacts to one shutter only align again in horizontal dirction (check at control window)
	Delay zero-position outside scan range	Check at wider scan ranges. Compensate with “SCANOFFSET”.

6. Laser Safety

Please, exercise extreme caution when using laser beams. Avoid all direct and scattered radiation.

For the transportation of the autocorrelator, the SHG-Crystal must be removed, in order to prevent damage to the crystal. Instructions for exchanging the crystal are on page 25 (6.8 exchange wavelength range) .For autocorrelators with scanranges bigger than 50 ps, a transport protection should be installed in the autocorrelator, in order to protect the scanner device against vibrations.

Appendix

Description of Serial Interface of Autocorrelator PulseCheck

The PC-control of the autocorrelator by means of a serial interface is done by commands consisting of ASCII strings. They either cause changes of the operation status (control commands) or the transmission of another ASCII-string containing the displayed autocorrelation data or a information about the actual status (parameters).

<u>Parameter of RS232</u>

Baudrate	4800 bps
Databits	8
Parity	non
Stop bits	1
No Handshake	

<u>Cable</u>

Autocorrelator	PC
2 TXD	RXD 2
3 RXD	TXD 3
5 GND	GND 5
1 DCD	DCD 1
6 DSR	DSR 6
4 DTR	DTR 4
7 RTS	RTS 7
8 CTS	CTS 8

List of Commands

The data transfer is released by sending the command „G" (47 Hex) to the serial interface. 267 Byte with following format will be sent back to the PC, containing ACF data and actual parameters.

Byte	Value	Meaning
0 ... 255 (in free/trig mode)	8 bit data values	ACF trace
0 ... 127 (in fringe mode)	8 bit data values	Envelope ACF trace top
128 ... 255	8 bit data values	Envelope ACF trace down
257	02 H	Free run / filter off
	06 H	Free run / filter on
	08 H	Trigger
	10 H	Fringes / resolution 128
	14 H	Fringes / resolution 64
258	01 H / 02 H / 04 H / 08 H / 10 H	Scan Range: 128 fs / 512 fs / 1,536 ps / 5,12 ps / 15,36 ps
259	01 H / 02 H / 04 H / 08 H / 10 H	Average: none / 2 / 4 / 8 / 16
260	8 bit data value	FWHM (in pixel)
261	8 bit data value	Crystal angle
262	8 bit data value	Signal offset
263	8 bit data value	Scan offset